QUARTERLY REPORT

(for January 1 - March 31, 1998)

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OCEAN OBSERVATIONS WITH EOS/MODIS
Algorithm Development and Post Launch Studies

by

Howard R. Gordon
University of Miami
Department of Physics
Coral Gables, FL 33124

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I shall describe developments (if any) in each of the major task categories.

1. Atmospheric Correction Algorithm Development.

a. Task Objectives:

During CY 1998 there are seven objectives under this task. Objectives (i) and (ii) below are considered to be the most critical. If the work planned under objective (i) is successful, a module that enables the algorithm to distinguish between weakly- and strongly-absorbing aerosols will be included in the atmospheric correction algorithm.

(i) We will continue the study of the "spectral matching" algorithm. The initial realization of the algorithm will be to provide a flag that will signal the probable presence of absorbing aerosols, and indicate that the quality of the derived products cannot be assured. Later realizations will provide an atmospheric correction in the presence of absorbing aerosols.

(ii) We need to test the basic implementation of the MODIS atmospheric correction algorithm with actual ocean color imagery. We will do this with SeaWiFS imagery.

(iii) We must implement our strategy for adding the cirrus cloud correction into the existing atmospheric correction algorithm. Specific issues include (1) the phase function to be used for the cirrus clouds, (2) the details of making two passes through the correction algorithm, and (3) preparation of the required tables. These issues will be addressed as time permits in CY 1998.

(iv) The basic correction algorithm yields the product of the diffuse transmittance and the water-leaving reflectance. However, we have shown that the transmittance depends on the angular distribution of the reflectance only when the pigment concentration is very low and then only in the blue. We need to develop a model to include the effects of the subsurface BRDF for low-pigment waters in the blue.

(v) We need to study the efficacy of the present atmospheric correction algorithm for removal of the aerosol effect from the measurement of the fluorescence line height.

(vi) We need to examine methods for efficiently including earth-curvature effects into the atmospheric correction algorithm. This will most likely be a modification of the look-up tables for the top-of-the-atmosphere contribution from Rayleigh scattering.

(vii) We will examine the necessity of implementing out-of-band corrections to MODIS.

b. Task Progress:

(i) We consider this task to be one of our most important atmospheric correction activities of 1998 [the other is item (ii) above: testing MODIS algorithms with SeaWiFS imagery], and as such, the major part of our effort on atmospheric correction will be focussed on it. During this quarter, we have began carrying out the necessary radiative transfer simulations required to prepare the look up tables (LUTs) for operation of the spectral matching algorithm described in the Appendix to the July-December 1997 Semi-Annual Report. In this algorithm, power-law size distributions are utilized. This allows us to use straightforward interpolation to size distributions that are not part of the candidate set. We also interpolate on the real and imaginary parts of the complex refractive index. Thus, a complete spectrum of models can be generated from a relatively small candidate set. We then use standard optimization techniques to find the best fitting set of parameters.

Thus far approximately 200,000 separate radiative transfer simulations have been completed. This effort consumed much of our and R. Evans' computer resources during this quarter. It is now clear to us that we need more computation resources. These will be requested in the near future. The LUTs resulting from these simulations can also be used in the standard atmospheric correction algorithm if desired.

(ii) We are acquiring SeaWiFS imagery on a regular basis and, with R. Evans, are preparing an end-to-end test of the performance of the MODIS algorithm in its present state. To effect this we have created a set of SeaWiFS-specific LUTs, but in a format required by the MODIS code. Evans' group has reformated SeaWiFS imagery into the MODIS format and thus we can test the MODIS codes using SeaWIFS-simulated MODIS data.

(iii) No work was carried out on this task.

(iv) No work was carried out on this task.

(v) No work was carried out on this task.

(vi) No work was carried out on this task.

(vii) We have recently received the MODIS relative spectral response (RSR) functions from MCST. These are being incorporated into the algorithms following the procedures described by Gordon (1995) ["Remote sensing of ocean color: a methodology for dealing with broad spectral bands and significant out-of-band response", Applied Optics, 34 8363-8374 (1995)].

c. Anticipated Activities During the Next Quarter:

(i) We will continue preparations to test the new spectral matching algorithm using SeaWiFS imagery.

(ii) With R. Evans, we will complete the end-to-end test of the MODIS code using SeaWifs imagery.

(iii) None. The cirrus cloud issue in the presence of our "spectral matching" method needs to be explored. We will resolve the "spectral matching" questions first.

(iv) None.

(v) None.

(vi) None. However, during the SeaWiFS initialization cruise (MOCE-4) there was a significant amount of imagery acquired at very large scan angles (> 55 deg.) coincident with surface measurements. These data will provide an exacting test of the adequacy of the earth-curvature correction.

(vii) We will (1) prepare new LUTs for the Rayleigh scattering component, (2) provide a set of Ozone absorption coefficients, (3) provide a set of weighted extraterrestrial solar irradiances, and (4) derive the functions needed to incorporate the out-of-band influence on the aerosol component of the atmospheric correction algorithm.

d. Publications:

R. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Use of the Junge power-law aerosol size distribution with variable refractive index to handle aerosol absorption Applied Optics, (Accepted).

2. Whitecap Correction Algorithm (with K.J. Voss)

As the basic objectives of the experimental portion of this task has been realized (acquiring whitecap radiometric data at sea), experimental work is being suspended until the validation phase, except insofar as the radiometer will be operated at sea when sufficient number of personnel are available. Our goal is to maintain experience in operating and maintaining the instrumentation in preparation for the validation phase of the contract. In addition, we need to reanalyze the Tropical Pacific whitecap data to better bound the limits of oceanic whitecap reflectance.

a. Near-term Objectives:

Operate the radiometer at sea to maintain experience in preparation for the validation phase. Reanalyze data acquired during the Tropical Pacific cruise.

b. Task Progress:

An undergraduate student was hired and developed what we believe is a rational technique for reanalyzing the Tropical Pacific data.

The radiometer was operated during the MOCE-4 cruise in support of SeaWiFS initialization when whitecaps were present.

c. Anticipated Activities During the Next Quarter:

We will begin the reanalysis of the Tropical Pacific data with the goal of submitting a revised manuscript on whitecap reflectance by the end of the summer.

d. Publications:

K.D. Moore, K.J. Voss, and H.R. Gordon, Spectral reflectance of whitecaps: Instrumentation, calibration, and performance in coastal waters, Jour. Atmos. Ocean. Tech., 15, 496-509 (1998).

3. In-water Radiance Distribution (with K.J.Voss)

The main objective in this task is to obtain upwelling radiance distribution data at sea for a variety of solar zenith angles to understand how the water-leaving radiance varies with viewing angle and sun angle.

a. Near-term Objectives:

Acquire data with this instrument during the MOCE-4 cruise in support of the SeaWiFS initialization effort.

b. Task Progress:

Data were acquired simultaneously with SeaWiFS overpasses at ~ 3/4 of the MOCE-4 cruise stations. We are reducing and evaluating this data. During the July 1997 cruise we had an opportunity to take an extensive data set during one afternoon, in which data was acquired with sun angles varying from approximately 40 degrees to 85 degrees. This will provide a good data set for evaluating the effect of sun angle on the upwelling radiance distribution, i.e., bidirectional effects, near the MOBY site.

c. Anticipated Activities During the Next Quarter:

We will continue to evaluate and work with the data acquired during both cruises. Our focus will first be on the MOCE-4 cruise, as the results will have an impact on our other work through its importance to SeaWiFS initialization.

d. Publications: None.

4. Residual Instrument Polarization.

The basic question was, if the MODIS responds to the state of polarization state of the incident radiance, given the polarization-sensitivity characteristics of the sensor, how much will this degrade the performance of the algorithm for atmospheric correction? We developed a formalism which provides the framework for removal of instrumental polarization-sensitivity effects, and an algorithm for removing much of the error induced by the polarization sensitivity.

a. Near-term Objectives: None.

b. Task Progress: None

c. Anticipated Activities During the Next Quarter:

Incorporate SBRS/MCST polarization-characterization data (when available) into our module for correcting for the MODIS residual instrument polarization.

d. Publications: None

5. Pre and Post-launch Atmospheric Correction Validation and Vicarious Calibration/Initialization (with K.J. Voss)

a. Task Objectives:

The objectives of this task are four-fold:

(i) First, we need to study aerosol optical properties over the oceans to assess the applicability of the aerosol models used in the atmospheric correction algorithm. Effecting this required obtaining long-term time series of the aerosol optical properties in typical maritime environments. This was achieved using a CIMEL sun/sky radiometer. This radiometer is identical to those used in the AERONET Network (of which we are a participant).

(ii) Second, we must be able to measure the aerosol optical properties from a ship during the initialization/calibration/validation cruises. The CIMEL-type instrumentation could not be used (due to the motion of the ship) for this purpose. The required instrumentation consisted of an all-sky camera (which can measure the entire sky radiance, with the exception of the solar aureole region) from a moving ship, an aureole camera (specifically designed for ship use) and a hand-held sun photometer.

In the case of strongly-absorbing aerosols, we have shown that knowledge of the aerosol vertical structure is critical. Thus, we need to be able to measure the vertical distribution of aerosols during validation exercises as well as to build a climatology of the vertical distribution of absorbing aerosols. This is accomplished with a LIDAR system, which we have modified for ship operations.

(iii) The third objective was to determine how accurately the radiance at the top of the atmosphere can be determined based on measurements of sky radiance and aerosol optical thickness at the sea surface. This required a critical examination of the effect of radiative transfer on "vicarious" calibration exercises.

(iv) The forth objective is to utilize data from other sensors that have achieved orbit (OCTS, POLDER, SeaWiFS ...) to validate and fine-tune the correction algorithm.

b. Task Progress:

(i) We have been operating the CIMEL instrument in the Dry Tortugas continuously during most of the quarter. It is working well, however the temperature sensor appears not to be working. We extracted specific days of the data set, believed to be dust, marine aerosol, or Non-Seasalt Sulfate aerosols. On these days we are running our inversions method to compare with that used by Nakajima (i.e., used in the Aeronet Network). This work is continuing.

(ii) We acquired sky radiance and aureole data with the instruments during the MOCE-4. We have performed the post calibration of these instruments (after a shipping delay) and are now reducing this data to radiometric units and extracting the almucantor and principal plane scans.

We deployed the LIDAR during the MOCE-4 campaign, and it performed flawlessly. We have performed inversions on the days of the SeaWiFS satellite overpasses.

(iii) The theoretical aspects of this work have been completed. The next phase is to use surface measurements to predict top-of-atmosphere radiance.

(iv) Our work under this objective is described under Section 1-ii.

c. Anticipated Activities During the Next Quarter:

(i) We will continue to keep the CIMEL operating in the Dry Tortugas, including the monthly maintenance checks. We will also try to correct the temperature problem, however it may be best to wait until we are swapping instruments for calibration to correct this problem. We are also continuing our work inverting the CIMEL data to determine the aerosol phase function.

(ii) We will be focusing on reducing the MOCE-4 data. The MOCE-4 cruise pointed out some shortcomings in our backup instrumentation for both the sky radiance and the iin-water radiance distribution camera systems. We will be rectifying this situation as is possible during the next 2 quarters in anticipation of the MODIS validation cruise.

(iii) We will use data acquired during MOCE-4 to attempt a vicarious calibration SeaWiFS Band 8 (865 nm).

(iv) We anticipate processing SeaWiFS imagery with MODIS code.

d. Publications:

H. Yang and H.R. Gordon, Retrieval of the Columnar Aerosol Phase Function and Single Scattering Albedo from Sky Radiance over Land: Simulations, Applied Optics, 37, 978-997 (1998).

6. Detached Coccolith Algorithm and Post Launch Studies.

a. Near-term Objectives:

The algorithm for retrieval of the detached coccolith concentration from the coccolithophorid, E. huxleyi is described in detail in our ATBD. The key is quantification of the backscattering coefficient of the detached coccoliths. Our earlier studies focused on laboratory cultures to understand factors affecting the calcite-specific backscattering coefficient. A thorough understanding of the relationship between calcite abundance and light scattering, in situ, will provide the basis for a generic suspended calcite algorithm. As with algorithms for chlorophyll, and primary productivity, the natural variance between growth related parameters and optical properties needs to be understood before the accuracy of the algorithm can be determined. To this end, the objectives of our coccolith studies during this previous 3 months have been:

1) Work-up results from our November '97 Cruise 2) Finalize data merging and processing for all previous cruises 3) Preparation and publishing of earlier results.

b. Task Progress:

For perspective on the directions of our work, I provide a brief overview of our previous activities. During 1995, we focussed on the optical properties of coccolithophores using chemostat cultures (in which algal growth rate was precisely controlled). During the latter half of 1995, our work focused on shipboard measurements of suspended calcite and estimates of optical backscattering as validation of the laboratory measurements. We participated on two month-long cruises to the Arabian Sea, measuring coccolithophore abundance, production, and optical properties. During 1996, we focused again on an examination of coccolith optics, during three Gulf of Maine cruises, one in March, one in June, and one in November. During 1997, we continued processing samples from our previous cruises, upgraded our laser light scattering photometer used in all of the calcite scattering measurements, performed two pre-launch cruises during which we estimated calcite particle optics in the Gulf of Maine, and analyzed our results from the MODIS-funded flow cytometer work. It should be noted that during the first cruise of 1997, we provided some of the only sea-truth numbers for the now defunct Japanese OCTS instrument.

Work performed this quarter

1) Processing of the CHN from the November '97 cruise. We are still processing the suspended calcite samples, which will be important for algorithm development activities.

2) Our flow cytometer manuscript submitted to J. Geophysical Research in the last quarter of 1997. Reviews were received in January, and revisions were complete by March 1997. The manuscript has been now returned to JGR pending final acceptance.

3) Continued microscope cell/ coccolith counts for samples from the Gulf of Maine. We are processing count data from June '97, and working on enumeration of November '97 samples.

4) During the past two years, we have collected a huge amount of data on calcite distributions in the Gulf of Maine. Merging of all the various types of data was becoming time consuming, so we generated new software to automate the process. We are now virtually completely caught-up in the merging of the optical and chemical data.

5) We participated with the Univerisity of Miami MODIS group (headed by Dr. Robert Evans) to verify final algorithm output prior to launch.

c. Anticipated Activities During the Next Quarter

1) We are finishing the last data analyses for the Arabian Sea work prior to beginning the first of two manuscripts.

2) Continue microscope cell/ coccolith counts for water samples from the November Gulf of Maine cruise.

3) We will go to sea in June on the last MODIS pre-launch cruise in the Gulf of Maine. The cruise will load on 25 May, and finish by 12 June, 1998.

4) Suspended calcite samples from the Gulf of Maine November '97 cruise still must be run in the graphite furnace atomic absorption spectrometer at the University of Maine.

8) A manuscript covering the March, June and November 1996 Gulf of Maine cruises has been completed, internally reviewed and is awaiting final editorial changes by my post-doc, L. Graziano, before submitting for publication.

9) We are upgrading our underway system for MODIS post-launch cruises which will be done on a ship of opportunity, the M/V Scotian Prince.

d. Publications:

There was one peer-reviewed publication published in the last quarter. The complete citation is:

Balch, W. M. and B. Bowler. Sea surface temperature gradients, baroclinicity, and vegetation gradients in the sea. J. Plank. Res.19: 1829-1858.

A technical report also was published:

Falkowski, P.G., M. J. Behrenfeld, W. E. Esaias,W. M. Balch, J. W. Campbell, R. L. Iverson, D. A. Kiefer, A. Morel, and J. A. Yoder. 1998. Satellite primary productivity data and algorithm development: A science plan for mission to planet earth. SeaWiFS Technical Report Series, NASA/TM-1998-104566, Vol. 42. Goddard Space Flight Center, Greenbelt, MD. 37pp.

Two manuscripts were submitted or revised for publication:

Balch, William M., David T. Drapeau, Terry L. Cucci, and Robert D. Vaillancourt, Katherine A. Kilpatrick, Jennifer J. Fritz. Optical Backscattering by Calcifying Algae. Revised for J. Geophys. Res.

Esaias, W. E., M. R. Abbott, O. W. Brown, J. W. Campbell, K. L. Carder, D. K. Clark, R. L. Evans, F. E. Hoge, H. R. Gordon, W. M. Balch, R. Letelier, and P. Minnett. An overview of MODIS Capabilities for Ocean Science Observations. Submitted to Transactions on Geoscience and Remote Sensing, EOS-AM Special Issue.

Several manuscripts are in preparation:

Campbell, J., D. Antoine, R. Armstrong, W. Balch, R. Barber, and others. Comparison of algorithms for estimating primary productivity from surface chlorophyll temperature and irradiance. In preparation for Global Biogeochem. Cycles.

Fritz, J. and W. Balch. Verification of carbon-14 calcification rates of the coccolithophore Emiliania huxleyi using scanning electron microscopy. To be submitted in the next quarter.

Graziano, L., W. Balch, D. Drapeau, B.Bowler, and S. Dunford. Organic and inorganic carbon production in the Gulf of Maine. To be submitted to Cont. Shelf Res.

Milliman, J., F. MacKenzie and W. Balch. Biologically-mediated dissolution above the lysocline- a major loss of oceanic calcium carbonate in the global ocean. To be submitted to Nature.